U.S. NAVAL SCHOOL OF AVIATION MEDICINE AND RESEARCH
NAVAL AIR STATION
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RESEARCH REPORT

REVIEW OF EXISTING DATA ON THE INCIDENCE OF DECOMPRESSION ILLNESS IN PERSONNEL AT AND BELOW 30,000 FEET.

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INTRODUCTION

Information concerning the lowest altitude range where the military flyer may experience symptoms of decompression due to rapid ascent, is of much importance in deciding the levels of cabin or cockpit pressurization required in military aircraft. The evidence, thus far, suggests that the range from 20,000 to 30,000 feet is critical in-as-much as decompression symptoms are slight below 20,000 feet and severe above 30,000 feet. Hence, a review of the information available in the literature dealing with the incidence of symptoms of decompression illness at this altitude range is timely. There are data showing the incidence and severity of symptoms at 20,000, 23,000, 25,000, 26,000, 28,000 and 30,000 feet. There are case reports of the occurrence of symptoms of decompression illness at as low an altitude as 10,000 feet.

There are a large number of variables which influence the incidence and severity of symptoms of decompression. In a group of healthy young males, such as comprise the personnel in military aviation, many of these variables are unimportant. There are four and perhaps five major ones, however, which are very important in determining the incidence and severity of decompression illness symptoms in aviation.

The first of these variables is an obvious one and concerns the factor of altitude gained or degree of decompression. The greater the decompression the more marked are the symptoms from both the standpoint of incidence and severity. This variable influences also the time of onset of symptoms.

A second major variable is the rate of ascent or the rate of change of decompression. Slow ascent or decompression permits the body to adjust to the changing environment and so permits the maintenance of a dissolved gas equilibrium with the ambient atmospheric pressure. In future aircraft employing human beings as pilots the rate of decompression will be such that little opportunity will be afforded for adjusting to this changing environment. Indeed, there are aircraft now available capable of creating this situation. The importance of this factor in the light of recent work on explosive decompression may not be important.

The third important variable is that of the duration of the exposure. A certain length of time is necessary for the development of symptoms which varies inversely with the increasing altitude. It will be seen in some of the results of experiments already performed that serious symptoms of decompression illness may appear as early as ten to fifteen minutes after reaching altitudes as low as 30,000 feet. Then too, if one is a

"resistant" individual and has endured the exposure without symptoms for two to three hours, he has demonstrated his ability to adjust to this new ambient pressure and has reached equilibrium with respect to dissolved gases.

The fourth major factor is that of exercise. It has been demonstrated repeatedly that the degree of activity is almost directly proportional to the incidence and severity of symptoms. Quite often, long exposures can be tolerated at high altitudes when the individual is at rest. The same individual, if physically active, often suffers severe symptoms even at lower altitudes.

The fifth factor, frequency of exposure, is not well understood and there is no general agreement regarding its significance. At lower altitudes, below 30,000 feet, habituation may develop, resulting in a progressive increase in tolerance to these altitudes for the person exposed. However, at altitudes above 30,000 feet, probably habituation may not exist, but rather a progressive decrease in tolerance to frequently repeated exposures.

An attempt will be made to outline the probable incidence of decompression illness, both mild and severe, at and below 30,000 feet. This discussion will chiefly take into consideration the two most important variables previously mentioned, namely, degree of decompression and exercise. The other three variables can be referred to only occasionally, because of the incompleteness of or variability in the available data. Even with regard to the type and severity of exercise, there is so much variation that evaluation is difficult. Thus, the type of exercise per se may often be responsible for mild muscle and joint distress. Deep knee bends is an example of exercise which falls into this category. Knee bending is not a usual exercise for airmen. Such exercise creates a problem in diagnosis in-as-much as it may cause symptoms not readily distinguishable from the mild aching in joints due to decompression.

REVIEW OF DATA

INCIDENCE OF SYMPTOMS AT 20,000 FEET AND BELOW

Allan's (1) findings of instances of decompression illness at altitudes as low as 10,000 feet (cited in report number one) were in patients who had recent joint injury or osseous pathology. However, persons so

injured or incapacitated would not be in active flight status. Therefore, for all practical purposes, such results can be disregarded. However, it is realized that injury during the flight may be a precipitating factor.

Houston's [2] results dealing with instances of joint pain and visual disturbances at altitudes of from 17,000 to 20,000 feet is likewise not directly applicable to the problem because of the age of the subjects and the frequency of exposure.

The results of decompression to altitudes of 20,000 feet are described in reports number one and two of this series [3]. In these studies young healthy subjects were rapidly decompressed 10,000 feet per minute and allowed to remain at 20,000 pressure altitude for thirty minutes, twice daily, over a period of nearly a month. During the exposure, moderate exercise was performed. In the first study the knee bending type of exercise was employed. However, since mild symptoms due to this type of exercise per se was thought possible, the exercise in the second experiment was changed to raising the feet alternately to a height of 18 inches once every second. This exercise continued for 30 seconds and was performed every five minutes. The exercise was felt to be much easier but more like that employed by an aviator operating an aircraft.

As a result of these repeated decompressions over an extended period very mild symptoms were noted. No severe symptoms were encountered and the incidence and severity of the symptoms did not change as the result of these frequent exposures. Fatigue was the only symptom which increased in incidence, but since this decreased later, it may suggest some degree of adaptation. It would seem, therefore, that pressurazation of cabin or cockpit at levels up to 20,000 feet equivalent altitude would not result in severe symptoms of decompression, nor would there be an accumulative effect from repeated frequent exposures other than, possibly, fatigue.

INCIDENCE OF SYMPTOMS AT 23,000 FEET

J.S. Gray [4] has studied the influence of exercise on the incidence of decompression illness at 23,000 feet. His subjects were aviation cadets, all healthy young males. The rate of ascent to altitude was 4,000 feet per minute. While at 23,000 feet, each subject exercised every five minutes. The exercise consisted of five deep knee bends and five push-ups against the low pressure chamber wall. All "flights" were planned for either one or two hours duration. The time at which descent was necessary, because of severe decompression illness, is not noted in their reports. In one group of 195-man flights, in which the exposure was meant to be of two hours duration, 12.8% had mild symptoms. There

were no severe symptoms. In another group of 117-man flights, in which the exposure was to last one hour, 6.8% had mild symptoms and 0.9% had severe symptoms.

It is seen that with moderate exercise of the knee bending and arm push-up type the incidence of severe decompression illness at 23,000 feet is negligible. It is, therefore, permissible to assume that if cabins or cockpits are pressurized to 23,000 feet, one may expect mild symptoms of decompression illness, but rarely any severe symptoms.

INCIDENCE OF SYMPTOMS AT 25,000 FEET

Several studies have been made at 25,000 feet altitude. Gray and Masland (5) have presented data which is based on 128-man exposures of two hours duration. The rate of ascent was 4,000 feet per minute. The exercise consisted of five deep knee bends and five push-ups against the low pressure chamber wall every ten minutes. There are no data presented as to the time of failure during these exposures. The data demonstrate that 10.2% suffered "mild" decompression illness symptoms and that the incidence of severe symptoms was 1.6%.

Mackensie and Riesen (6) studied the effect of decompression to 25,000 feet on a group of enlisted personnel and two officers in the Air Corps. The average age of the enlisted subjects was 23 and the two officers were aged 30 and 36. All were in good health. The exposures were two to four days apart. The rate of ascent was 3,000 feet per minute with oxygen used from 18,000 feet with the auto-mix on. The exercise consisted of five deep knee bends and five arm bends holding a fourteen-pound weight. The exercise was performed every ten minutes. No severe bends symptoms occurred.

Ferris, Webb, Engel, and Brown (7) in a study emphasizing the variables of exercise, altitude, and denitrogenation found that when they exercised their subjects every three minutes, doing five deep knee bends at 25,000 feet, the incidence of severe bends was the same as at 35,000 feet in resting subjects. Symptoms, of such severity as to require descent, occurred in 10% of the individuals after periods of exposure range from 55 minutes to two hours.

It is apparent that an increase in the incidence of symptoms has taken place when 25,000-feet exposures at 25,000 feet are compared with

exposures at 23,000 feet. The factor of exercise is seen to be very important in bringing about the increase in incapacitation. The incidence of decompression illness in a group performing moderate exercise from one to two hours would be sufficient to be a definite problem. The incidence in the resting or light exercise group would probably not be a factor at 25,000 feet.

INCIDENCE OF SYMPTOMS AT 26,000 FEET

There are two reports available on the specific incidence of decompression illness at 26,000 feet. One report by Mackensie and Riesen [6] using an identical experimental procedure described as having been used by them at 25,000 feet, gave an incidence of incapacitating symptoms of 21%.

In another report by Smedal at al [8], in which a large number of aviation cadets were given an exposure of 20 minutes duration at 26,000 feet following an ascent at the rate of 5,000 feet per minute, 17% of the exercising subjects experienced mild symptoms and 1.4% had severe symptoms. In the resting group there were no severe symptoms, 1.5% had mild distress.

In the above mentioned studies it is readily seen that the experimental design differs considerably. The amount and severity of both the exercise and the exposure are not similar. Since these are two of the most important etiologic factors in decompression illness, the discrepancy in the percent incidence of symptoms is easily explained.

INCIDENCE OF SYMPTOMS AT 28,000 FEET

Mackensie and Riesen [6] used the same group as previously described during the review of the results of decompression to 25,000 feet in a study at 28,000 feet. The experimental plan called for an ascent at a rate of 3,000 feet per minute to maximum altitude using oxygen from 18,000 feet. The exercise was again five deep knee bends and five arm bends holding a fourteen-pound weight and was performed every ten minutes. As the result of this type of exposure, severe decompression illness symptoms were found in from 28% to 41% of the subjects. Smedal, Brown and Hoffman [8] exposed 65 men, once only, to 28,000 feet for twenty minutes. The rate of ascent to this altitude was 5,000 feet per minute and the subjects exercised every three minutes performing five

deep knee bends and five arm bends without holding a weight. The decompression chamber was at room temperature. The per cent incidence of severe symptoms of decompression illness was 12.3. A similar 12.3% experienced mild symptoms.

The factor of exercise again determines to what degree severe decompression illness symptoms will occur at this altitude. The difference in the results of the two above mentioned experiments lies in the difference in the degree of exercise. In exercising airmen, it is obvious that a considerable number will experience severe decompression illness symptoms at 28,000 feet.

INCIDENCE OF SYMPTOMS AT 30,000 FEET

Ferris, Webb, Engle, and Brown (7) found that the total incidence of symptoms at 30,000 feet, when subjects exercised every three minutes, doing five deep knee bends, was the same as at 35,000 feet. However, the number of forced descents at 30,000 feet was much lower than at 35,000 feet. These forced descents at 30,000 feet began as early as twenty minutes at altitude. Twenty per cent of the subjects were forced to descend by thirty minutes and 35% by the end of sixty minutes.

In 135-man exposures at 30,000 feet following an ascent at 4,000 feet per minute, during which the subjects did five deep knee bends and five push-ups against the chamber wall, Gray and Masland (5) found an incidence of 15.5% severe bends which forced descent.

Smedal, Brown, and Hoffman (8) as the result of observing 92-man flights to 30,000 feet for twenty minutes each, during which the subjects exercised every three minutes, doing five deep knee bends and five arm bends, found an incidence of 11.5% severe "bends" pain and 18% mild "bends" pain. In resting subjects, of which there were 214-man flights, there was no severe "bends" pain at 30,000 feet and only 4.3% of mild symptoms.

The following data (9) obtained recently at Pensacola are offered with a view toward predicting the probable incidence of symptoms of decompression illness at an altitude of 30,000 feet. Seven hundred and fifty-three persons experienced a twenty-minute exposure to a simulated altitude of 30,000 feet in a decompression chamber. The temperature, while at this degree of decompression, averaged -30° F. Half of the 753 persons exercised and the other half rested. The exercise consisted

in doing five deep knee bends and five arm bends every three minutes. Ninety-three individuals experienced severe joint distress. Of the 93, 69 were in the exercising group. The location of the pain, probably because of the type of exercise, was for the most part in the knees; 46 subjects localizing the pain in the knee. This incidence of 12.3% with severe joint pain compares favorably with an earlier report [8] of an incidence of 11.5% severe bends symptoms in exercising personnel at a simulated altitude of 30,000 feet.

SUMMARY AND DISCUSSION

It is obvious that symptoms of decompression will result from the exposure of persons to altitudes of from 20,000 to 30,000 feet. At 20,000 feet, few or no severe symptoms of decompression will result, even if the subjects are moderately active. Between altitudes of 20,000 and 25,000 feet and with exercise, the incidence of severe decompression illness symptoms will undoubtedly be low. At 25,000 feet, with the additional factor of exercise, incapacitating symptoms will occur in a small percentage of persons. Again, the actual incidence will depend in a large part upon the amount of activity on the part of the individual. When altitudes of 28,000 and 30,000 feet are reached, it has been shown that the incidence of severe decompression illness symptoms in exercising subjects may vary from 10% to 40%. The efficiency of flyers, in aircraft with internal cockpit or cabin pressurized at 28,000 to 30,000 feet, will depend considerably on the amount of physical work involved. If the activity is little, the great majority can expect to remain for long periods at a pressure altitude of 30,000 feet without symptoms of severe decompression illness. The variable of repetition of exposure, which is felt to be important and of which we still know very little, may prove to be a deciding factor in military aviation with regard to the incidence of symptoms of decompression illness. Such repeated exposures have been seen to result in a fitigue problem. A revival of the altitude tolerance classification, substituting repeated for single exposures in decompression chambers in order to find their tolerance to decompression, might prove worthwhile.

CONCLUSION

Pressurization of aircraft cockpits and cabins to a pressure altitude of 30,000 feet will result in the production of symptoms of decompression illness. The severity of the symptoms and hence the probability of incapacitation will be directly proportional to the amount of physical activity carried out by the individual occupying such a cabin or cockpit. Pressurization of aircraft cockpits and cabins to altitudes below 30,000 feet will progressively lower the incidence and severity of symptoms of decompression illness. It is unlikely that very severe symptoms will be encountered at altitudes below 23,000 feet in military aviation.

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